# Arterial Conduits for Coronary Artery Bypass

Noel Mills and John Pigott

The use of arterial conduits in coronary artery bypass has increased steadily since it became clear that the internal thoracic artery offered an increased success of the operation. A number of arterial grafts have been tried or suggested in recent years. The fate of all grafts depends on nontechnical factors that have often been ignored, yet impact late results. Recent data has pointed out that low-density lipoprotein (LDL) cholesterol should be <100 mg/dL and triglycerides should be <150 mg/dL, with less emphasis on total cholesterol values. Lp(a), a thrombogenic molecule, has not been properly addressed. Ideally, its value should be <5 mg/L and studies reveal that 90% of the population in the United States has an Lp(a) less than 18 mg/L. Its importance is magnified when it is associated with a high LDL. Grafts and native arteries bathed in a lipid milieu are programmed for earlier failure.

Patients living with a hypercoagulable state are not uncommon, yet we find that they are less often identified. Antithrombin III deficiency may or may not be noted upon heparinization for cardiopulmonary bypass.

Measurement of preoperative antithrombin III levels has allowed for early diagnosis and appropriate treatment in the postoperative period. Activated protein C (APC) resistance (Factor V Leiden) is an inherited disorder that occurs in approximately 5% of the general population. Screening protocols for hereditary thrombotic disorders should include testing for APC resistance. Approximately 80% of arterial clotting may involve high levels of Lp(a).

Because these disease states may directly influence the results of coronary artery bypass grafting, it is important to screen patients appropriately and treat those in which hypercoagulable states are confirmed.

## Right Internal Thoracic Artery Anastomosed to the Right Coronary Artery System

The right internal thoracic artery (ITA) has been advocated as a bypass graft either as a pedicle or free graft. Invariably, the right has not had the success of its counterpart, the left ITA. The lack of success of that particular conduit is caused by a number of problems, many of which are anatomical and/or technical. The pathology of human coronary atherosclerosis is such that there is often significant disease at the origin of the posterior descending coronary artery. Likewise, the right coronary artery (RCA) may be sizable and, in fact, disproportionately larger than the distal right ITA that is being anastomosed to it. The anatomy of the RCA (Fig 1) is quite variable, thereby making it basically impossible to compare right ITA grafts to the RCA system with left ITA grafts to the much more anatomically consistent left anterior descending coronary artery. For example, a right ITA graft anastomosed to the RCA proximal to the point of takeoff of the posterior descending artery has significant double jeopardy. The atherosclerotic disease process has a propensity to increase with time in the distal right coronary and in the proximal posterior descending, itself. Likewise, if the right ITA is anastomosed to the midportion of the posterior descending artery, it may be at a point in which the right ITA is 1.5 mm in diameter or smaller or it may be stretched, leading, of course, to a poor result.

Aside from these anatomical and pathological considerations, right ITA grafts are indicated in patients who have a paucity of vein graft material and especially in young patients with premature atherosclerosis, many of whom have elevated homocysteine levels. Part of the postoperative treatment of the latter group of patients should be oral folic acid, 2 to 5 mgm/day plus B vitamins.

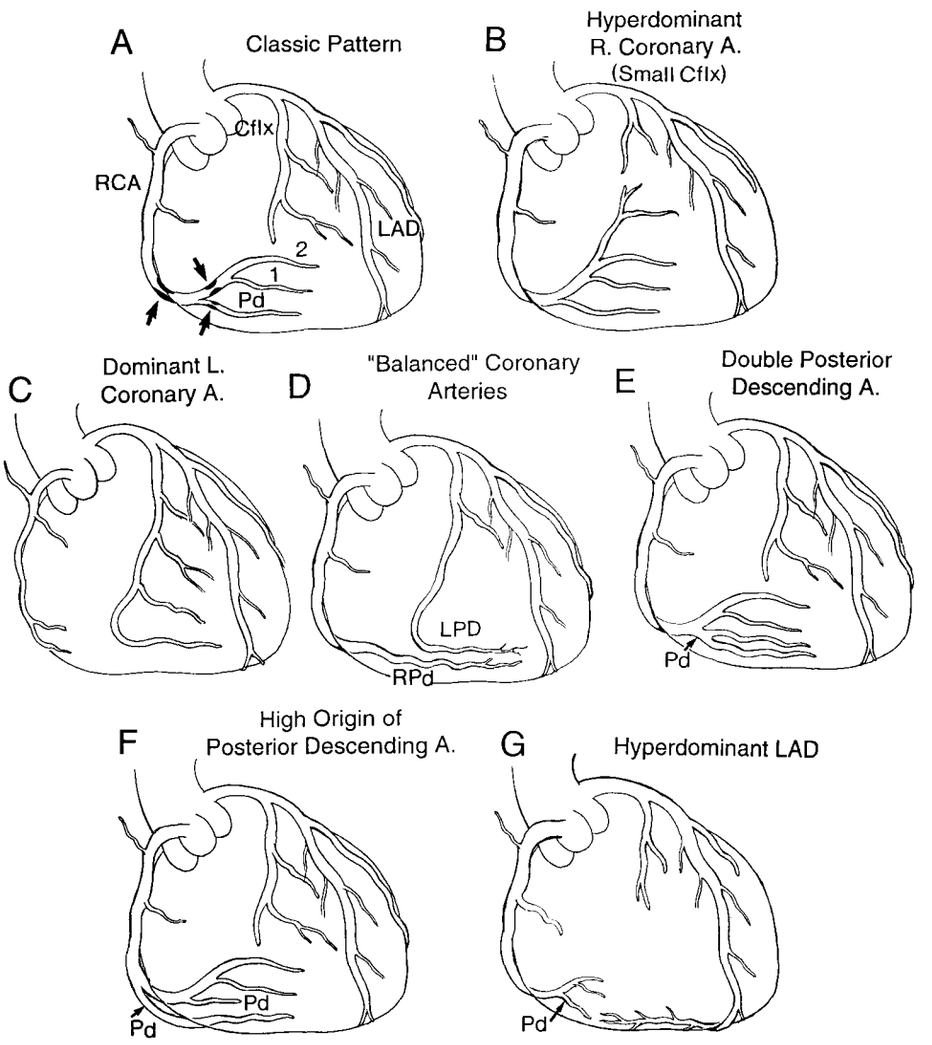
Some contraindications for pedicle right ITA grafting are unequal arm blood pressures (BPs) (right <20 mmHg than left), subclavian bruits, and known right subclavian artery stenosis/occlusion. Right ITA grafts are generally not used if life expectancy is less than 8 to 10 years, ie, the longevity of good quality saphenous grafts.

Much has been written about preparation of ITA grafts. It is our strong opinion that all ITA grafts should have intraoperative measurement of free flow to insure that there will not be a problem of inadequate mammary flow. Preparation of ITA grafts with body temperature intraluminal papaverine has been used since the early 1970s. Careful aspiration is carried out to confirm perfect placement of the intraluminal needle, and the blood buffers negate any concern regarding the pH of papaverine. Overzealous hydrostatic dilatation is not used; rather, the papaverine solution is left in the graft during pericardiotomy and cannulation to allow the patient's blood pressure to effect most, if not all, of the dilatation. If a free flow of 120 cc/min with a systemic BP of 100 mmHg is not obtained, a problem of proximal atherosclerosis, technical error, injury, etc. exists and the ITA is used as a free graft. Other injury from harvest may not be recognized early; intimal damage (thermal) from the electrocautery is probably the single most common cause of a late postoperative string sign.

Generalized ITA narrowing from competition of flow when vessels with marginal stenoses are bypassed is the second most common cause of late string sign. Stretch injury from heavy-handed manipulation is the most frequent cause of ITA dissection. This usually occurs midway during harvest when small tributaries are avulsed at their origin. Often, the ITA is not easily seen after the sternum is elevated. It may be safely exposed inferiorly by grasping the transverse thoracic muscle, pulling it away from underside of the chest wall, and performing a myotomy. The ITA is easily seen because it is not adherent to that muscle, and dissection may proceed superiorly. The usual preferred site for target coronary anastomosis is the upper posterior descending coronary artery.

## Anatomical Configurations of the RCA

The RCA is inconsistent in its anatomical configurations (Fig. 1). This makes comparisons of that vessel to the left anterior descending (LAD), which has a consistent anatomy, very difficult.



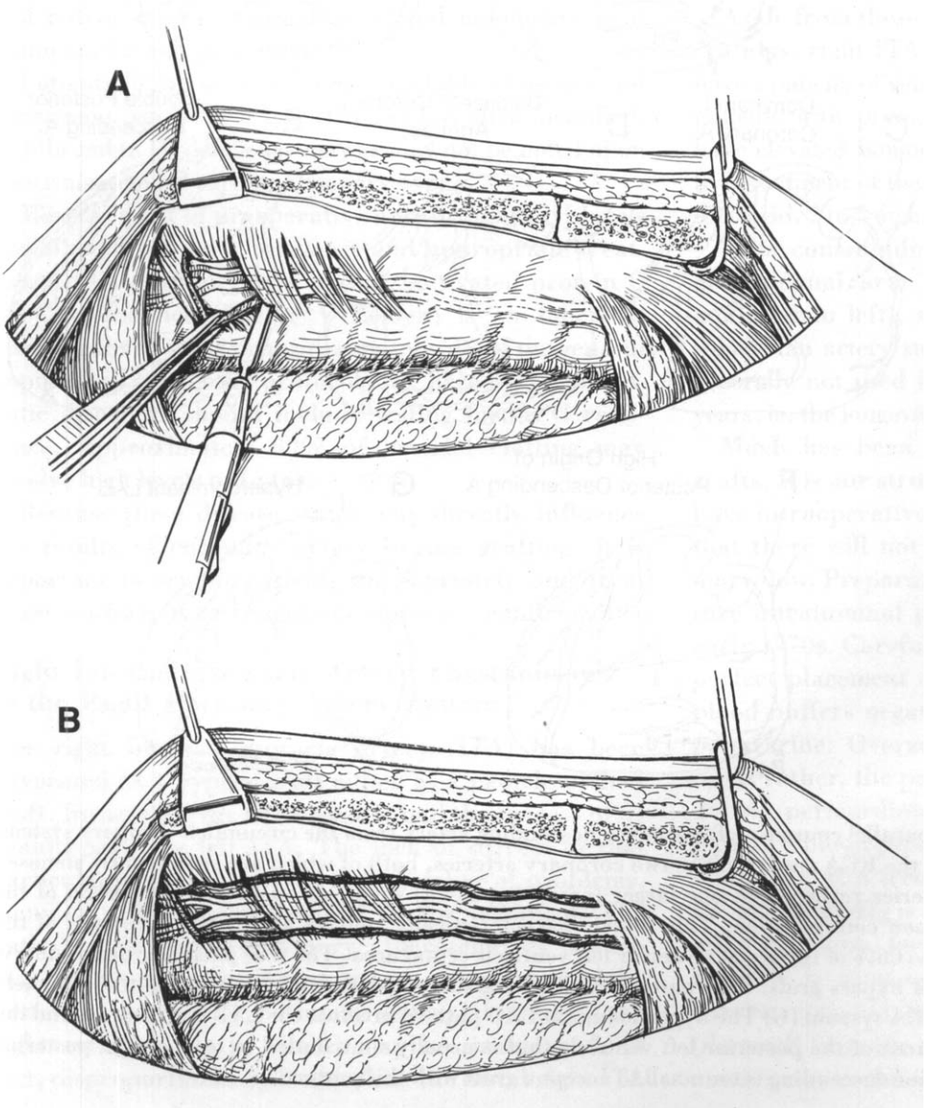

**1** (A) In the classic pattern that occurs in only 50% to 60% of patients, the posterior descending arises at the crux of the heart and supplies the ventricular septum and the posterior left ventricle. The extent of left ventricular supply varies and depends on the number of inferior ventricular (posterolateral) branches that arise from the distal RCA. The predilection for atherosclerotic involvement (arrows) at specific points makes revascularization with a single graft and one anastomosis impractical in most instances. Therefore, the RCA cannot be compared with the LAD, which can be bypassed with a single ITA in the vast majority of patients. (B) The hyperdominant RCA pattern may not only supply the posterior left ventricle septum, but may take over areas that are usually supplied by the circumflex system. (C) The dominant left coronary artery configuration is associated with a RCA that contributes only to varying amounts of perfusion to the right ventricle and zero to the left ventricle. A right RITA to the RCA is contraindicated in this anatomical pattern. (D) In the balanced coronary circulation, the right posterior descending is the only branch from the RCA that is supplying the left ventricle and is complimented by a parallel coursing left posterior descending artery from the circumflex coronary system. (E) A double posterior descending from the RCA may result in two coronary arteries, both of which are significantly stenosed proximally. The result is two small arteries rather than one larger (easily bypassed) single vessel. (F) A high origin of the posterior descending is not an uncommon configuration. This vessel characteristically courses across the bare area of the posterior right ventricle to supply 33% to 66% of the distal posterior left ventricle septal area. The true posterior descending is often diseased and too small to accept a bypass graft. This pattern offers a logistic problem for bypass grafts to completely revascularize the area supplied by the RCA system. (G) The hyperdominant LAD pattern involves the LAD coursing around the apex of the left ventricle to supply the area of the posterior left ventricle that is usually contributed to by the right posterior descending coronary artery. The posterior descending is too small to accept a graft with this pattern.

## SURGICAL TECHNIQUES

### RGEA Bypass to the RCA System

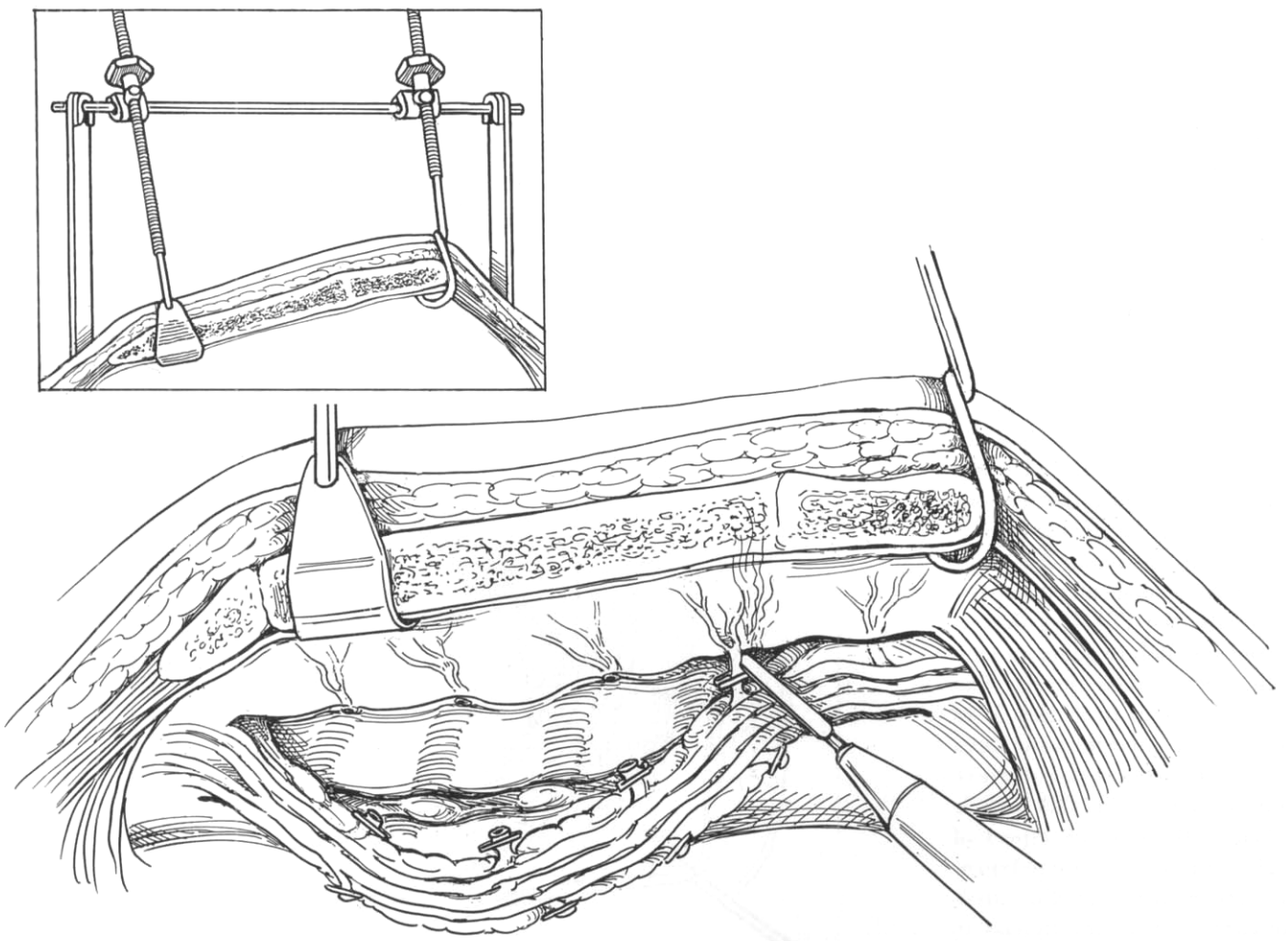
The right gastroepiploic artery (RGEA) has been used clinically in humans since the late 1980s and has been reported to have satisfactory early and midterm results. Physiological data continue to confirm its place as a significant additional arterial graft to the coronary bypass surgeon's armamentarium. Harvest is definitely more time consuming, although some minutes may be saved by simultaneous dissection with the ITA. An indications for its use is paucity of venous conduit, especially with patients undergoing repeat coronary bypass. Generally, the indications mirror those for use of the right ITA to the right coronary system. It has been used in young patients with Kawasaki disease by us and other investigators. We have found this graft particularly useful in conjunction with right ITA grafting in patients with ascending aortic atherosclerosis, in which a no-touch technique of the aorta is used. Contraindications for RGEA grafting include previous gastric resection. Patients with extreme obesity are poor candidates for its use as are those with abdominal visceral atherosclerosis. A prime consideration for RGEA grafting is the severity of coronary atherosclerosis. RGEA grafts to minimally stenotic coronary arteries are destined to become string signs because of competition of flow with the native circulation. This is more certain with the RGEA graft as opposed to other conduits because of their longer lengths. The physiological formula for flow ($F = 1/R$) emphasizes this point because resistance to flow (R) is directly proportional to length of graft.

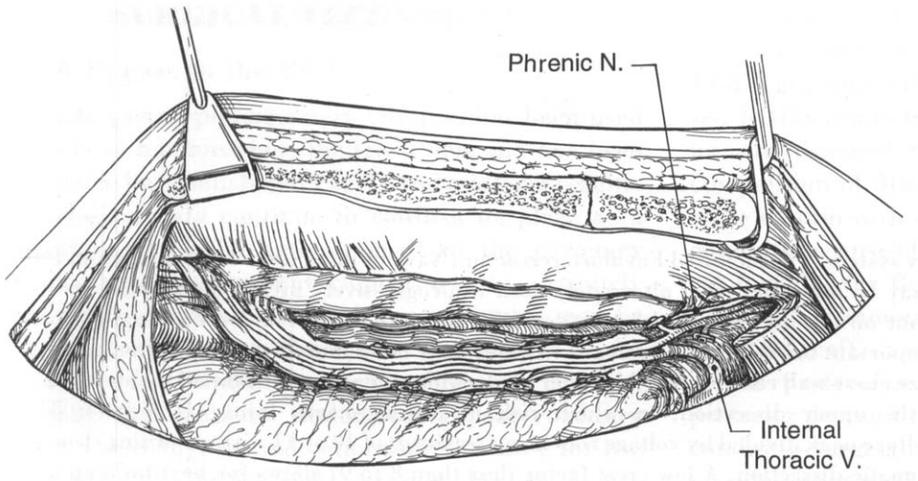
Our preference for RGEA anastomosis is to the posterior descending coronary artery. On occasion, this conduit is large and very long and the distal 5 to 9 cm may be transected and used as a separate free graft. The RGEA may be used as a sequential graft to two or more coronary branches only if it is 2.25 mm internal diameter (ID) or larger at the site for sequential anastomosis. Because the graft is relatively thin compared with other conduits, sequential anastomoses to smaller diameter sections of conduit tend to fail for technical reasons.




**2** ITA bypass to the right coronary system. (**A**) The dissection is begun by grasping the transversus thoracic muscle near the level of the xiphoid process, pulling it away from the chest wall, and opening it to expose the distal internal thoracic artery. This is the safest way to find and preserve the ITA to dissect it from its inferior to its superior aspect. If an injury occurs early during harvest, the graft may still be saved as a pedicle or free graft. This is the reason for beginning the dissection at the inferior end of the right ITA. (**B**) Two parallel lines are cut with the electrocautery 1 cm on either side of the ITA up to the level that the internal mammary veins deviate from the pedicle.

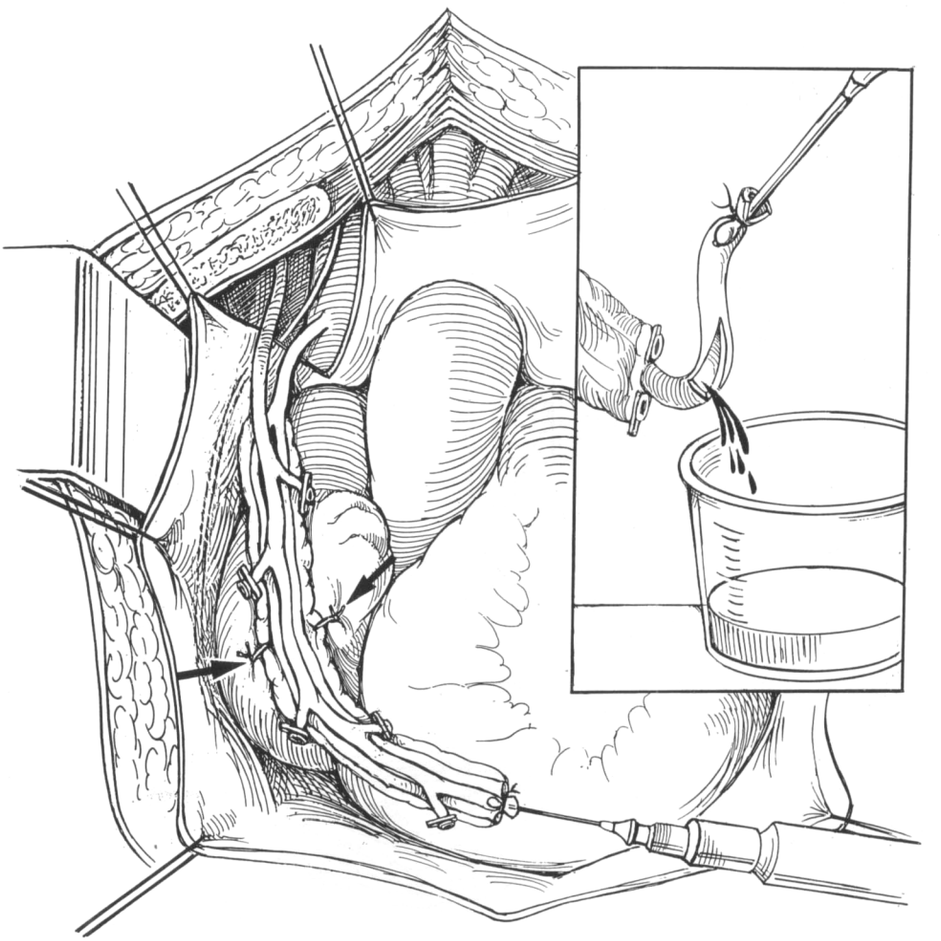
**3** ITA bypass to the right coronary system. The modified Favaloro retractor (Navco Pilling Co, Fort Washington, PA) is preferred because each handle may be separately and alternately used to progressively lift up the sternum as the dissection proceeds. Less stress is put on the cartilage and bony skeleton than with retractors with a fixed element between the retractor blades. It is important for the anesthesiologist to generously use a muscle depolarization agent at this point in the operation to maximize chest-wall relaxation. The upper blade is located around the top of the sternum to afford good visualization during the upper dissection, in which risk of phrenic-nerve injury is highest. The electrocautery with a crest factor (voltage peak divided by voltage root mean squared) of 10 or 11 with no cutting element is preferred to effect the most atraumatic dissection. A low crest factor (less than 8 to 9) allows for heat buildup and imprecise coagulation. If bubbles are seen in the internal thoracic vein, one can be sure that the "boiled blood" may be damaging the ITA intima with the ultimate result of a string sign. Hemostatic clips are used on the graft side, and the ITA tributaries are cut with the electrocautery close to the sternal wall so that the current will "spark out" on the chest wall and not on the graft side itself.



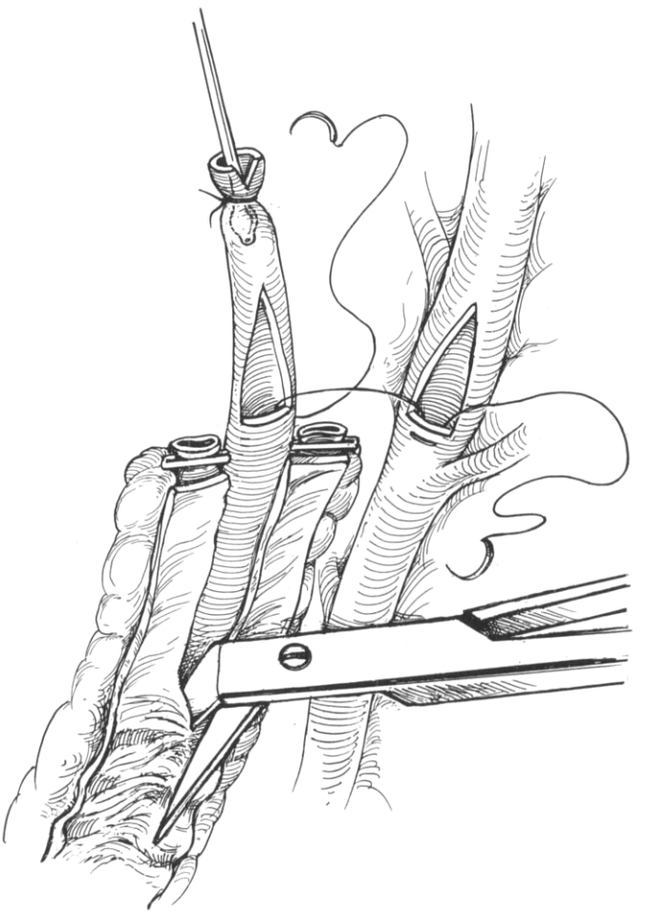


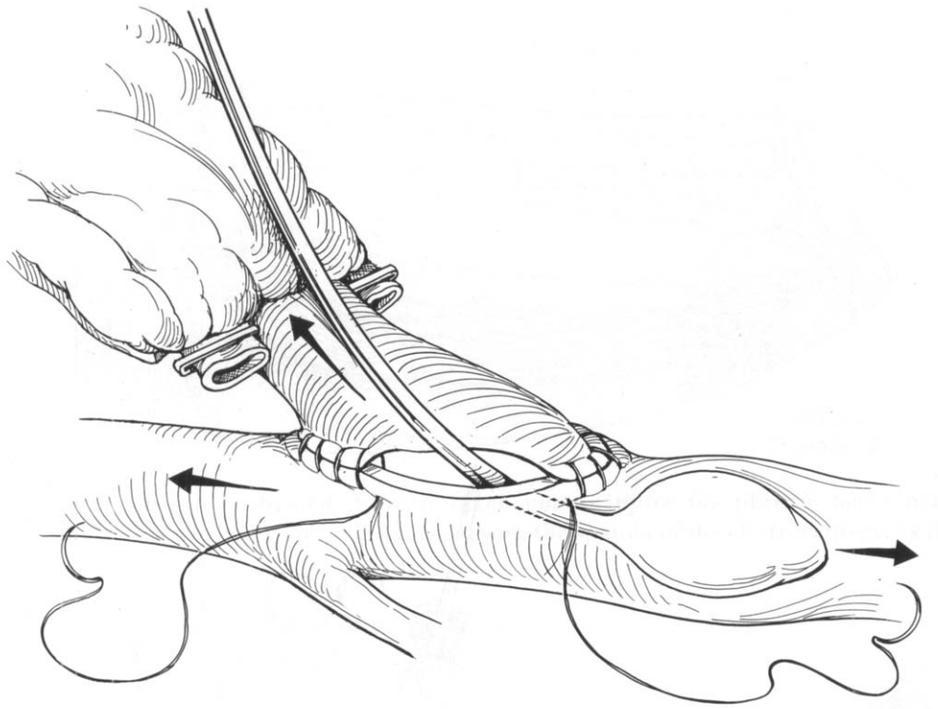

**4** After opening the intrathoracic portion of the sternothyroid muscle, the proximal ITA and internal thoracic vein are skeletonized proximally after they separate to their points of origin. This adds significant length to the graft. A consistent branch of the ITA arises medially (pericardiophrenic artery) and should be clipped and divided with scissors. Division with the electrocautery can easily transmit heat energy into the ITA because there is no noncontracting sternal tissue to ground out the electric spark. The distal end of the small artery can be cauterized once it is divided. Care is taken not to injure the phrenic nerve near the ITA origin. The dissection and skeletonization can be primarily performed with the spatula of the electrocautery, as the remainder of the ITA is branch free.

**5** If the free flow of the graft is less than 120 cc/min, the ITA is used as a free graft as opposed to a pedicle graft. A 1 mm olive-tipped needle is tied into the distal ITA or a side branch after it is divided and ligated distally. Three to 6 cc of 60 mgm of papaverine diluted in 60 cc of normal saline at body temperature is slowly, gently infused with a 3-cc syringe into the graft while the distal end is carefully inspected under 3.5 power loupe magnification. The end of the olive-tipped needle is kept immediately adjacent to the distal tie so that it does not abrade the intimal surface of the ITA and thus set up an area of dissection. The graft is set aside during cannulation so that the papaverine has time to pharmacologically dilate the ITA. Finally, the ITA free flow is measured just before going on cardiopulmonary bypass (inset). The pericardium is cut in a deep V to the level of the superior vena cava (SVC), with care taken not to injure the phrenic nerve. The ITA pedicle is tacked to the inferior aspect of the right atrium with a 5-0 polypropylene suture (arrows) before instituting cardiopulmonary bypass to insure that there will be a tension-free conduit with a full heart after cessation of cardiopulmonary bypass.

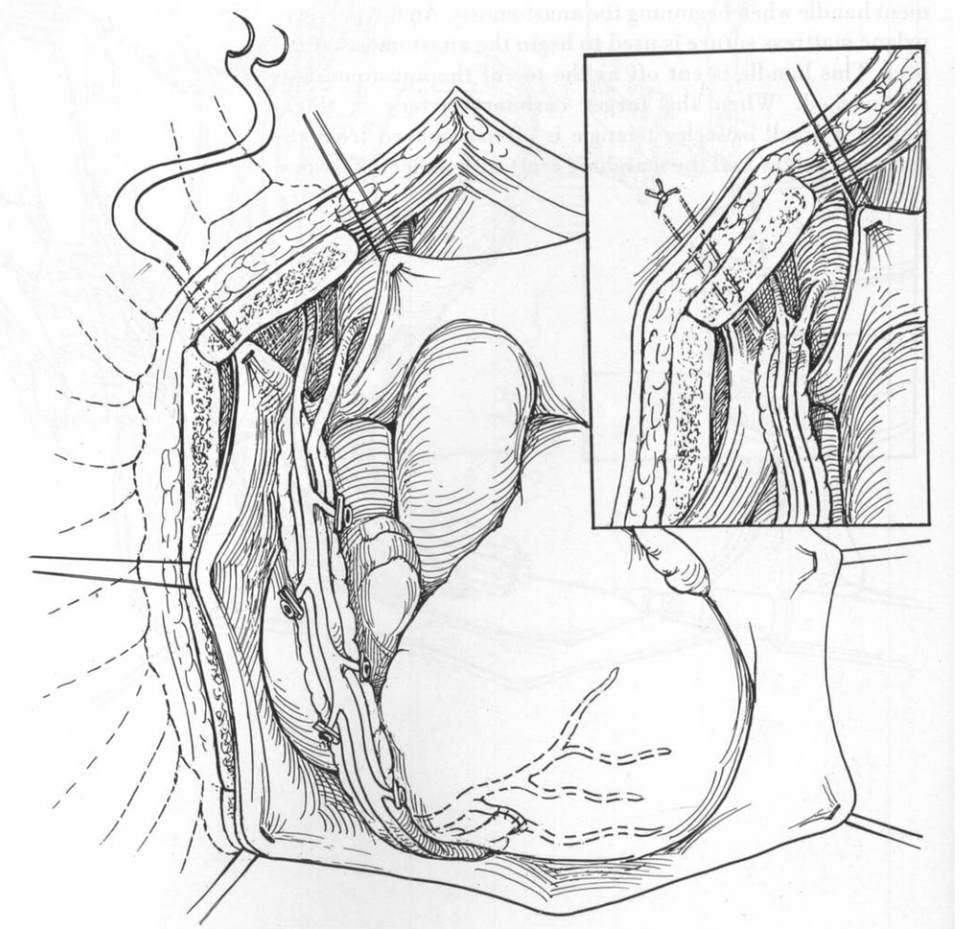


**6** The fascia on the ventral side of the pedicle graft is split proximally for a minimum of 7 cm. Often, bands of tissue contracted by the electrocautery are found crossing the artery and compressing it. The 1-mm diameter needle used for intraluminal papaverine instillation is left on as a convenient handle when beginning the anastomosis. An 8-0 polypropylene mattress suture is used to begin the anastomosis at the heel. This handle is cut off as the toe of the anastomosis is approached. When the target coronary artery is thick-walled, a small isosceles triangle is often removed from the coronary artery and the matching graft with delicate scissors.



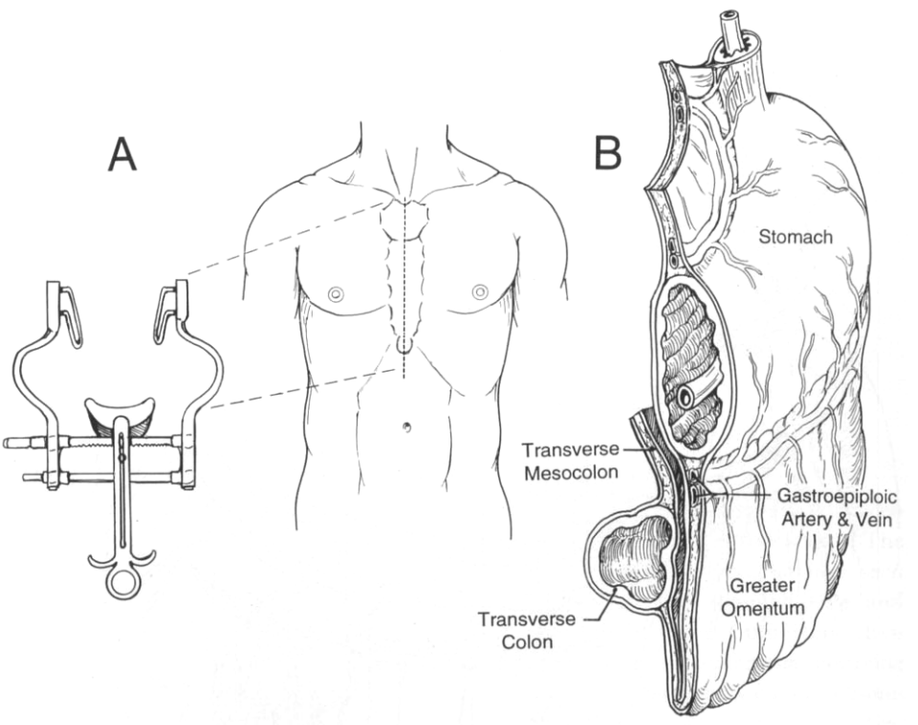


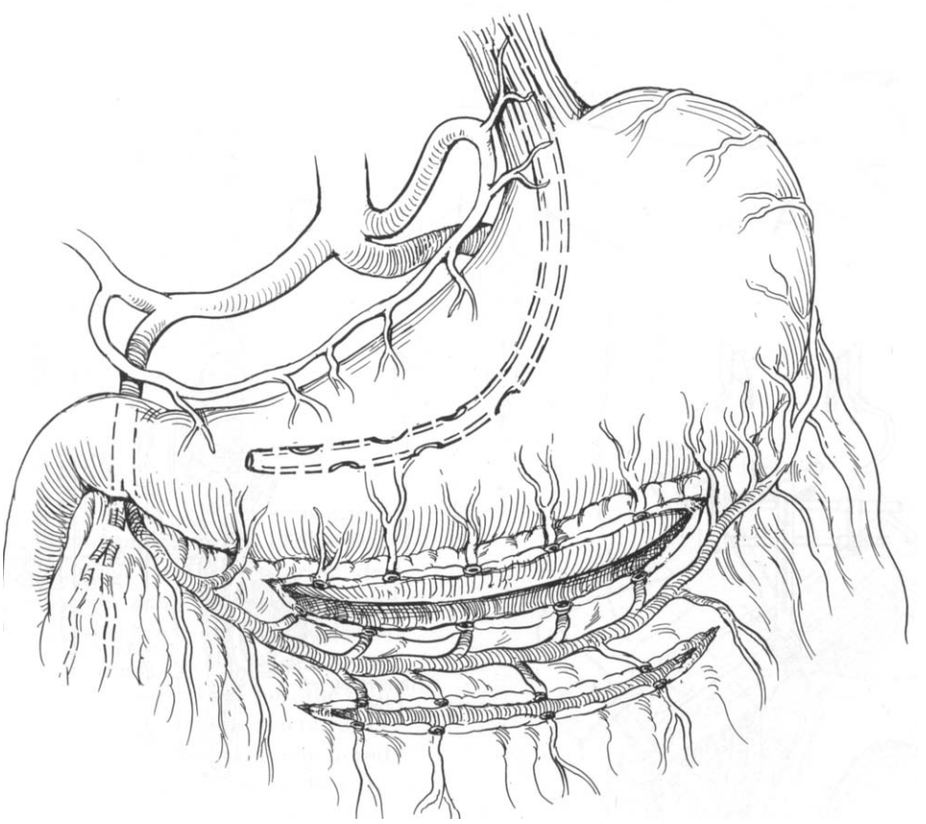
**7** The anastomosis is always completed on one side of the coronary artery. Patency is checked in all three directions and the internal diameters are recorded with an appropriately sized dual diameter probe before tying down the final sutures. The graft is tacked to the epicardium 2 cm from the anastomoses to insure that there will be no tension or tortion.



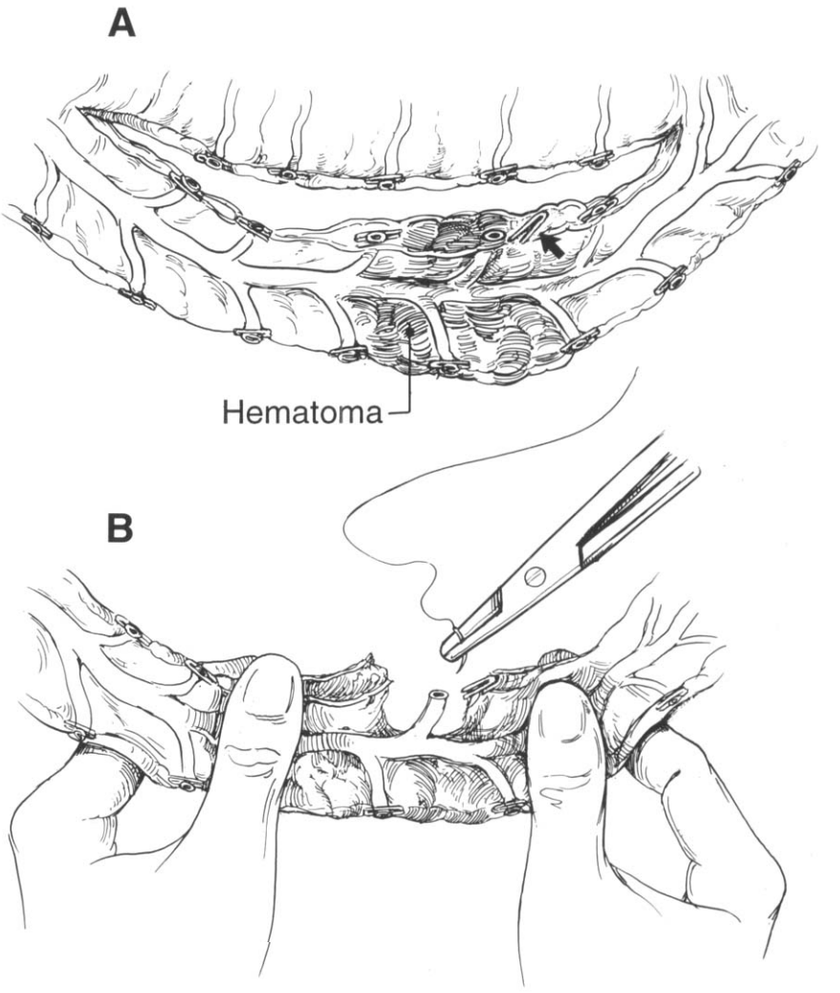
**8** The completed right ITA graft is anastomosed to the posterior descending coronary artery. Only rarely is it necessary to ligate and divide the internal thoracic vein to gain more length. More often than not, the vein is not the length-limiting factor after skeletonization. We have not found that multiple transections of the perigraft tissue along the length of the ITA offer much to gain more length. A convenient method to prevent hyperinflated lungs from stretching the pedicle graft is to tack the pericardial edge to the underside of the sternum (inset). This is accomplished by passing a straightened heavy needle on a #2 silk suture from outside the appropriate interspace through the pericardium adjacent to the split and again back through the interspace to be tied on the outside of the chest wall below the subcutaneous tissue.

**9** Right gastroepiploic artery bypass to the RCA system. (**A**) The medial sternotomy incision is extended no more than 2 to 3 cm from the usual length in the majority of cases. The peritoneum is opened transversely after sternotomy and the Balfour retractor is inserted in place with the bladder blade placed inferiorly. The stomach is left inflated and is grasped with Babcock clamps to deliver it into the operative field. Dissection is begun in the midportion of the stomach. The right gastroepiploic artery is inspected to insure that it has a palpable pulse and is of adequate size for bypass grafting. (**B**) Four serosal layers course from the stomach inferiorly and the right gastroepiploic artery is found between the most anterior and second layers. The accompanying vein is usually inferior to the artery in the midstomach area and assists in the location of the RGEA.

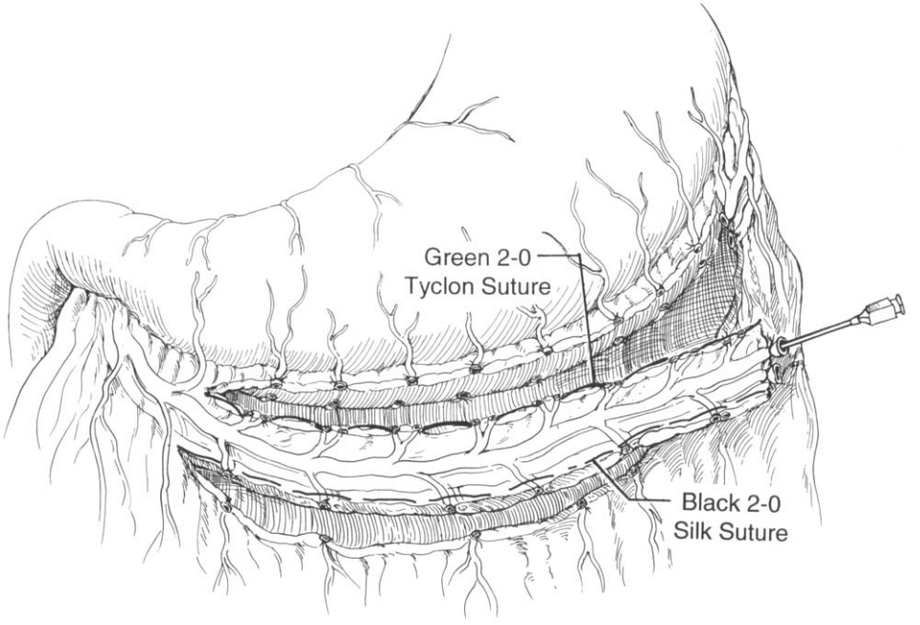




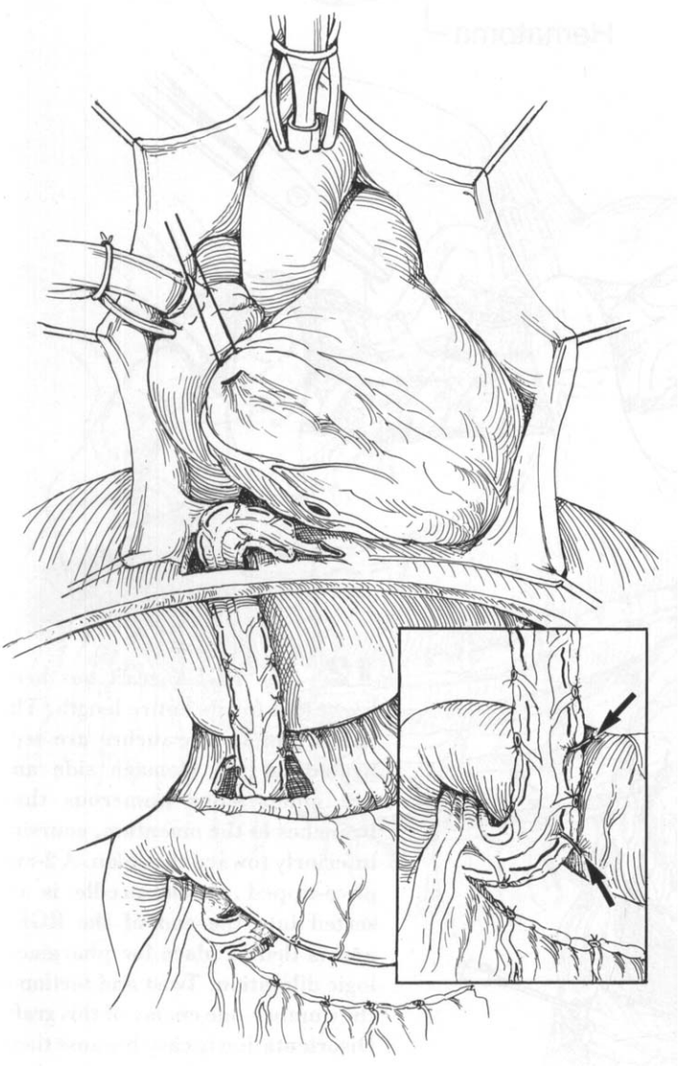
**10** RGEA. The anterior peritoneal layer is reflected from the midstomach region; gastric branches of the RGEA are ligated with 4-0 silk ties and divided. The RGEA is now bimanually palpated between fingers to confirm adequate size and pressure. Clips are avoided on the graft because they are prone to being avulsed during routing of the conduit to the target coronary artery within the pericardial cavity. Tying arterial branches has avoided completely the diagnostic problem of questionable intraabdominal bleeding in a patient who may have a period of hypotension and who may be on vasopressors in the early postoperative hours. Air in the stomach, which is usually present from anesthesia induction before intubation, often helps with exposure in patients with truncal obesity and is not aspirated until completion of graft harvest. The RGEA branches are tied individually rather than with mass ligature. RGEA harvest may be carried out by one surgeon while another takes down the ITA.



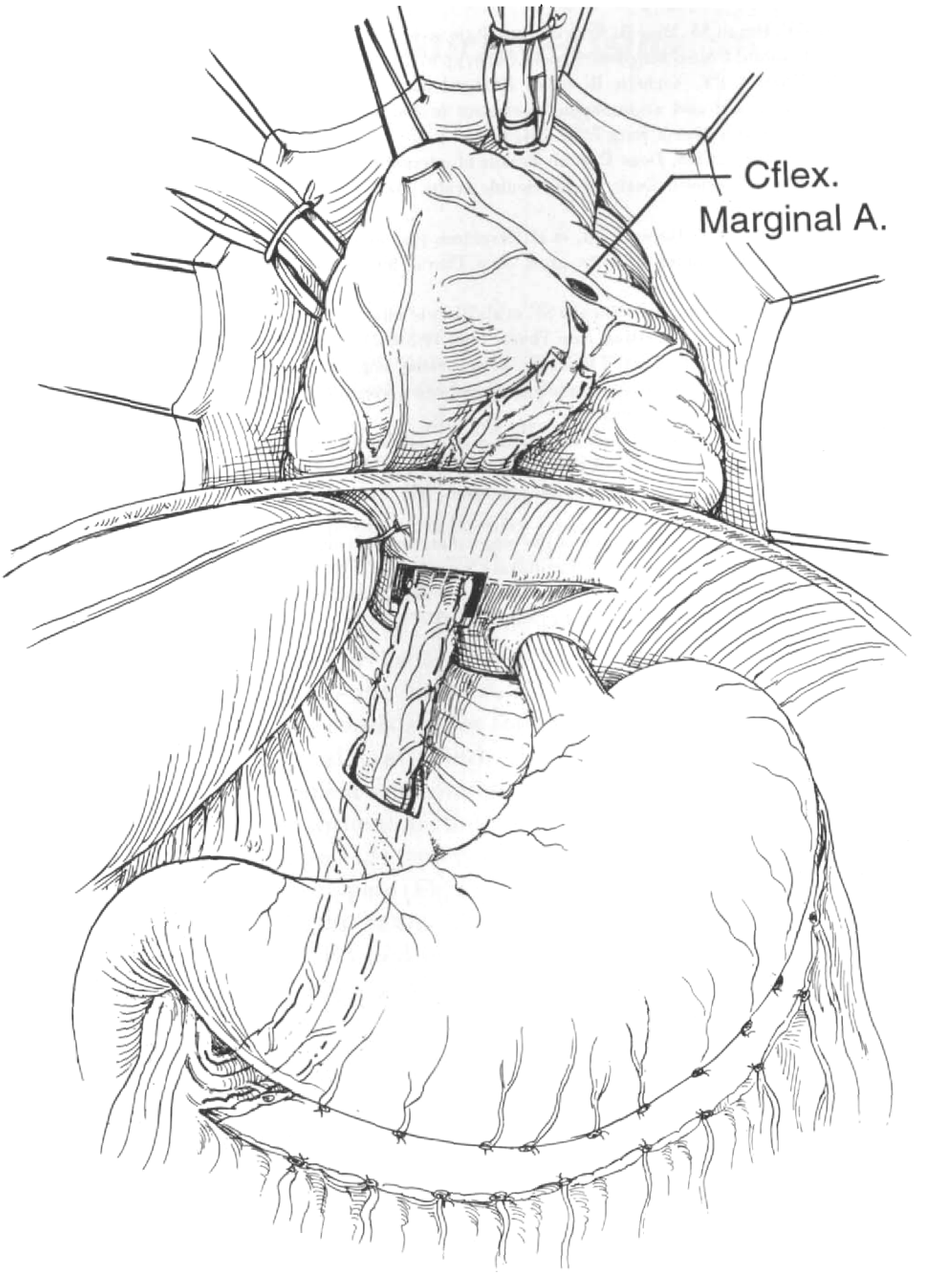

**11** (A) Mass ligature and/or vascular clips are associated with arterial branches getting loose and causing an immediate hematoma in the peritoneal layers and omental fat. This incurs an unnecessary hazard, as the graft may be injured during attempts to control hemorrhage. (B) These hematoma become large almost instantaneously because of the ease of extravasation of blood into the tissues, and they obliterate vision. This converts an otherwise smooth graft harvest into a miserable, time-consuming, and unwanted challenge. Control of such bleeding in friable branches adjacent to the RGEA are often difficult to identify. Should this occur, the graft should be temporarily occluded proximally and distally and the offending branch dissected out and identified. It is then sutured with a fine polypropylene vascular suture using loupe magnification.




**12** The RGEA graft has been harvested for its entire length. The paired epiploic branches are seen ligated on the stomach side and are much more numerous than branches in the omentum, coursing inferiorly toward the colon. A 2-mm olive-tipped plastic needle is inserted into the end of the RGEA and is tied in place for pharmacologic dilatation. Twist and tortion is the number-one enemy of this graft. Disorientation is easy because there are no landmarks, such as those found with the ITA graft. For that reason, a No. 2 black silk suture is permanently left on the greater curvature side (inferior), and a blue or green 2-0 tycron suture is left on the lesser curvature (superior) side of the graft as it is being harvested. The accompanying gastroepiploic vein is ligated at the distal (but not proximal) end of the graft. The proximal dissection is stopped at least 2 cm before the origin of the gastroduodenal artery. Dissection is never carried out near the pancreas. Five to 10 cc of 60 mgm papaverine in 60 cc body temperature normal saline is slowly infused into the graft. Intraluminal Diltiazem (Marion, Merrel & Dow, Kansas City, MO) may also be used if the RGEA seems especially prone to spasm. As with ITA grafts, free flow is measured before cardiopulmonary bypass.



**13** The diaphragm is opened with the electrocautery from above, with a sponge in the surgeon's hand held below to avoid damage to the left lobe of the liver. A 2 to 2.5 cm square diaphragmatic trapdoor allows adequate room for the graft without kink or compression. The diaphragmatic access is made in line with the inferior vena cava (IVC), which allows a comfortable lie of the graft, yet is not of size or position to invite internal herniation. The black silk marking suture is maintained to the left and inferior, and the colored suture is maintained to the patient's right and superiorly. In that way, a twist-free conduit is assured. In this diagram, the graft is routed posterior to the stomach after opening the lesser omentum through the lesser sac. Care is taken to open the lesser sac through an avascular window to avoid unnecessary bleeding from the gastric arterial branches. The graft may be routed anterior to the pylorus (inset). If so, care is taken to tack it anterior to the pylorus so that a postoperative gastric dilatation will not cause stretch and/or disruption of the graft. The graft to coronary anastomosis is performed with continuous 8-0 polypropylene suture. The perigraft tissue is tacked on each side of the anastomosis with a 5-0 suture. After redundant graft, tissue (ie, gastroepiploic vein and fat) is tacked just distal to the anastomosis to prevent any possible abnormal stress or disruption. Skeletonization of the distal RGEA near the anastomosis is scrupulously avoided because it is almost always associated with troublesome bleeding.




**14** When the RGEA is routed posterior and laterally to the circumflex coronary artery branches, a different route is used. The retrogastric course is mandatory. Access to the pericardial cavity is made through a more laterally placed window. The triangular ligament of the left lobe of the liver is divided, with care being taken to avoid damage to the hepatic veins. The cut edge of that ligament on the hepatic side is used to tack the liver lobe above the pericardial window to avoid compression by it on the conduit. After completing the anastomosis, the conduit is tacked to adjacent structures at several points along its length and especially at its entrance into the pericardium at the diaphragm window.

## COMMENTS

The ITA graft used for RCA system bypass in anatomically correct situations with good technical principles should have patency rates identical to left ITA grafts to the LAD. This has not been proven in the literature because right ITA grafts have been anastomosed to disease-prone areas in the RCA system or stretched beyond safe limits in attempts to bypass beyond atherosclerotic diseased sites. Likewise, because the RCA system is so anatomically variable, only infrequently will a single right ITA graft be sufficient to address all of the diseased RCA branches.

The Achilles heel of the RGEA graft is disorientation with subsequent twist and tortion. Because landmarks are scanty and the fatty pedicle may inadvertently be rotated, we strongly advise suture markers, which we have used without problem in over 200 cases. Abdominal operations post RGEA grafting are made safer with such landmarks. Anatomical and physiological considerations of the RCA system must be taken into account when using this graft.

## SUGGESTED READING

Angelina GE, Bryan JA, Dion R: Arterial conduits in myocardial revascularization. London, United Kingdom, Arnold, 1066, pp 67-77

Dion R, Etienne PY, Verhelst R, et al: Bilateral mammary grafting—clinical, functional and angiographic assessment in 400 consecutive patients. Eur J Cardiothorac Surg 7:287-294, 1993

Fiore AC, Naunheim KS, Dean P, et al: Results of internal thoracic artery grafting over 15 years: Single versus double grafts. Ann Thorac Surg 49:202-209, 1990

Galbut DL, Traad EA, Dorman HJ, et al: Seventeen year experience with bilateral internal mammary artery graft. Ann Thorac Surg 49:195-201, 1990

Kouchoukos NT, Wareing TH, Murphy SF, et al: Risks of bilateral internal mammary artery bypass grafting. Ann Thorac Surg 49:210-219, 1990

Lytle BW, Cosgrove DM, Loop FD, et al: Perioperative risk of bilateral internal mammary artery grafting analysis of 500 cases from 1971–1984. Circulation 74:37-52, 1986 (suppl 3)

Mills NL: Physiological and technical aspects of internal mammary artery coronary artery bypass graft, in Cohn LH (ed): Modern Techniques in Surgery: Cardiac–Thoracic Surgery. Mount Kisco, NY: Futura Publishing, 1982, pp 1-19

Mills NL, Bringaze WL: Preparation of the internal mammary artery graft. Which is the best method? J Thorac Cardiovasc Surg 98:73-77, 1989

Mills NL, Everson CT: Right gastroepiploic artery: A third arterial conduit for coronary artery bypass. Ann Thorac Surg 47:706-711, 1989

Mills NL, Everson CT: Technical considerations for use of the gastroepiploic artery for coronary artery surgery. J Cardiac Surg 4:1-9, 1989

Mills NL, Hockmuth DR, Everson CT, et al: Right gastroepiploic artery used for coronary artery grafting surgery. Evaluation of flow characteristics and size. J Thorac Cardiovasc Surg 106:579-585, 1993

Mills NL, Ochsner JL: Technique of internal mammary-to-coronary artery bypass. Ann Thorac Surg 17:237-246, 1974

Suma H: Spasm of the gastroepiploic artery graft. Ann Thorac Surg 49:168-169, 1990

Suma H, Fukumoto H, Takeuchi A: Coronary artery bypass grafting by utilizing in situ right gastroepiploic artery: Basic study and clinical application. Ann Thorac Surg 44:394-397, 1987

Suma H, Wanibuchi Y, Terada Y, et al: The right gastroepiploic artery graft: Clinical and angiographic mid-term results in 200 patients. J Thorac Cardiovasc Surg 105:615-623, 1993

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